



Urban Stormwater BMP Performance Monitoring

A Guidance Manual for Meeting the National
Stormwater BMP Database Requirements

April 2002



Urban Stormwater BMP Performance Monitoring

A Guidance Manual for Meeting the National Stormwater BMP Database Requirements

Prepared by

GeoSyntec Consultants
Urban Drainage and Flood Control District

and

Urban Water Resources Research Council (UWRRC) of ASCE

In cooperation with

Office of Water (4303T)
US Environmental Protection Agency
Washington, DC 20460
April 2002

EPA-821-B-02-001



TABLE OF CONTENTS

List of Tables.....	viii
List of Figures	x
Acknowledgements and Disclaimer	xi
1 INTRODUCTION	1
1.1 Scope.....	1
1.1.1 State of the Practice	2
1.1.2 The Need for Guidance	2
1.1.3 National Stormwater Best Management Practices Database	2
1.2 Format and Content of This Document	2
2 BMP MONITORING OVERVIEW	4
2.1 Context of BMP Monitoring in the Regulatory Environment	4
2.2 BMP Monitoring Goals.....	5
2.3 Physical and Chemical Characteristics of Stormwater Runoff.....	7
2.4 Stormwater Quality Monitoring Challenges	8
2.5 Complexities Specific to BMP Monitoring	9
2.5.1 Considerations for Evaluating BMP Effectiveness.....	10
Load Versus Water Quality Status Monitoring	10
Consideration of Parameters for Monitoring.....	12
2.6 BMP Types and Implications for Calculation of Efficiency	13
2.7 Relationship Between Monitoring Study Objectives and Data Analysis	14
2.8 Physical Layout and Its Effect on Efficiency and Its Measure	15
2.9 Relevant Period of Impact	16
2.9.1 Concentrations, Loads, and Event Mean Concentrations	17
2.9.1.1 Concentrations	17
2.9.1.2 Loads.....	17
2.9.1.3 Event Mean Concentrations	18
2.9.2 Measures of BMP Efficiency.....	18
2.9.2.1 Historical Approaches.....	21
Efficiency Ratio.....	21
Definition.....	21
Assumptions	23
Comments.....	23
Example.....	24
Summation of Loads	24
Definition.....	24
Assumptions	24
Comments.....	25
Example.....	25
Regression of Loads (ROL)	25
Definition.....	25

Assumptions	26
Comments.....	27
Mean Concentration	29
Definition.....	29
Assumptions	29
Comments.....	30
Efficiency of Individual Storm Loads	30
Definition.....	30
Assumptions	31
Comments.....	31
Summary and Comparison of Historical Methods	32
2.9.2.2 Other Methods and Techniques	32
“Irreducible Concentration” and “Achievable Efficiency”	32
Percent Removal Relative to Water Quality Standards.....	36
“Lines of Comparative Performance©”	37
Multi-Variate and Non-Linear Models.....	40
2.9.2.3 Recommended Method	40
Effluent Probability Method.....	40
2.9.2.4 Reference Watershed Methods	43
2.9.3 BMPs and BMP Systems	44
3 DEVELOPING A BMP MONITORING PROGRAM	45
3.1 Phase I – Determine Objectives and Scope of BMP Water Quality Monitoring Program	46
3.1.1 Monitoring and Literature Review to Assess BMP Performance.....	47
3.1.2 Monitoring to Assess Compliance with Surface Water quality criteria	49
3.1.3 Criteria for the Protection of Aquatic/Marine Life	49
3.1.4 Human Health	50
3.1.5 Application of Water quality criteria to Stormwater	50
3.1.6 Groundwater and Sediment Standards.....	51
3.1.7 Scope of Work for BMP Monitoring Program	51
3.1.8 Information Needs to Meet Established Goals of BMP Monitoring	55
3.2 Phase II – Develop BMP Monitoring Plan	56
3.2.1 Recommendation and Discussion of Monitoring Locations.....	56
Integration of BMP Monitoring into a Municipal Monitoring Program	57
Sampling from a Well Mixed Location.....	58
3.2.1.1 Upstream	59
3.2.1.2 Downstream	60
3.2.1.3 Intermediate Locations.....	60
3.2.1.4 Rainfall.....	61
Site Proximity.....	61
Number of Gauges.....	62
3.2.1.5 Groundwater	62
3.2.1.6 Sediment Sampling	63
3.2.1.7 Dry Deposition.....	63
3.2.1.8 Modeling Methods	64

Estimates of Water Quality Parameters.....	64
Estimates of Flow	67
Estimates of Rainfall	67
3.2.2 Recommendation and Discussion of Monitoring Frequency.....	68
3.2.2.1 Statistical Underpinnings of Study Design	68
3.2.2.2 Factors Affecting Study Design.....	69
Number of Samples	69
Determining the Number of Observations Needed	70
3.2.3 Recommendation and Discussion of Water Quality Parameters and Analytical Methods.....	76
3.2.3.1 Selecting Parameters.....	76
3.2.3.2 Dissolved vs. Total Metals.....	79
3.2.3.3 Measurements of Sediment Concentration	79
3.2.3.4 Analytical Methods.....	81
3.2.4 Recommendation and Discussion of Monitoring Equipment and Methods	83
3.2.4.1 Equipment	83
Data Loggers	83
Power Requirements	87
Flow	89
Volume-Based Methods	91
Stage-Based Methods	91
Manning’s Equation.....	92
Other Empirical Stage-Flow Relationships	93
Stage Based Method Using Weirs and Flumes.....	93
Stage-Based Variable Gate Meters	94
Velocity-Based Methods	94
Tracer Dilution Methods	95
Constant Injection Rate Tracer Dilution Studies	95
Total Recovery Tracer Dilution Studies	95
Pump Discharge Method.....	95
3.2.4.2 Automatic Sampling Techniques.....	96
Selection of Primary Flow Measurement Device.....	96
Types of Primary Flow Measurement Devices	96
Weirs.....	97
Flumes.....	97
Considerations for Selection of Primary Flow Measurement Device	99
Range of Flows	99
Flow Rate	100
Accuracy	100
Cost	100
Head Loss and Flow Characteristics.....	101
Sediment and Debris	101
Construction Requirements.....	101
Selection of Secondary Flow Measurement Device.....	102
Float Gauge.....	103
Bubbler Tube	103

Ultrasonic Depth Sensor	104
Pressure Probe.....	105
Ultrasonic “Uplooking”	106
Radar/Microwave.....	106
Equipment for Measuring Velocity.....	107
Methods Suitable for Calibration	107
Tracer Studies	108
Rotating-Element Current Meters.....	108
Pressure Sensors.....	108
Acoustical Sensors	108
Float-and-Stopwatch Method.....	109
Deflection (or Drag-Body) Method	109
Methods Most Suitable for Continuous Velocity Monitoring.....	109
Ultrasonic (Doppler) Sensors.....	109
Electromagnetic Sensors.....	110
Acoustic Path	111
Water Quality Sample Collection Techniques	111
Grab Samples	111
Composite Samples	112
Automatic Sampling.....	114
Automatic Sampling Equipment	115
Overland Flow Sampler.....	118
In-situ Water Quality Devices, Existing Technology	119
In-situ Water Quality Devices, Future Technologies	121
Ion-Selective Electrodes	121
On-Line Water Quality Analyzers	121
Particle Size Analyzers	122
In-situ Filtration and Extraction System	123
Remote Communications with Automatic Equipment.....	123
Manual Sampling	124
Manual Grab Sampling Equipment.....	125
Manual Composite Sampling Equipment.....	125
3.2.4.3 Error Analysis and Measurement Accuracy	126
3.2.5 Recommendation and Discussion of Storm Criteria.....	127
3.2.5.1 Storm Characteristics	127
3.2.6 Recommendation and Discussion of QA/QC	129
3.2.6.1 Sampling Methods	132
Contamination/Blanks	133
Reconnaissance and Preparations.....	134
Site Visits	134
Laboratory Coordination.....	134
Sample Containers/Preservation/ Holding Times	135
Recommended Field QA/QC Procedures.....	135
Field Blanks.....	135
Field Duplicate Samples.....	135
Field Sample Volumes	136

Chain of Custody.....	136
Recommended Laboratory QA/QC Procedures	136
Method Blanks	136
Laboratory Duplicates	136
Matrix Spike and Spike Duplicates	136
External Reference Standards	136
3.2.7 Recommendations for Data Management.....	137
3.2.7.1 Database Requirements.....	137
Analysis of Database Links	138
Analysis of Outlying Records	138
Sample Comparisons Between Original Documents and Final Data Set.....	139
Digital Conversion of Data.....	139
Double Data Entry and Optical Character Recognition	139
3.3 Phase III - Implementation of Monitoring Plan.....	139
3.3.1 Training of Personnel.....	139
3.3.2 Installation of Equipment.....	140
3.3.3 Testing and Calibrating Equipment	141
3.3.4 Conducting Monitoring.....	141
3.3.5 Coordinate Laboratory Analysis	143
3.4 Phase IV - Evaluation and Reporting of Results	144
3.4.1 Validate Data	144
3.4.2 Evaluate Results.....	144
3.4.2.1 Preliminary Data Evaluation.....	145
3.4.2.2 Definitive Evaluations	145
3.4.3 Report Results.....	146
3.4.3.1 National Stormwater BMP Database Requirements.....	147
3.4.3.2 Standard Format Examples	156
General Test Site Information	156
Watershed Information.....	159
Structural BMP Information.....	164
Non-Structural BMP Information	166
Detention Basin Design Data	169
Retention Pond Design Data	172
Percolation Trench and Dry Well Design Data.....	175
Media Filter Design Data	178
Grass Filter Strip Design Data.....	181
Wetland Channel and Swale Design Data.....	183
Porous Pavement Design Data	186
Infiltration Basin Design Data.....	189
Hydrodynamic Device Design Data.....	192
Wetland Basin Design Data	194
Monitoring Station Information	198
Precipitation Data	201
Flow Data	203
Water Quality Data.....	205
3.4.3.3 On-line Information	207

References208
Index214

- APPENDIX A
- APPENDIX B
- APPENDIX C
- APPENDIX D

List of Tables

	Page
Table 2.1: Objectives of BMP implementation projects and the ability of comprehensive water quality monitoring studies to provide information useful for determining performance and effectiveness	6
Table 2.2: Examples of water quality parameters and relevant monitoring period	17
Table 2.3: Summary of historical, alternative, and recommended methods for BMP water quality monitoring data analysis.....	20
Table 2.4: Example of ER method results for TSS in the Tampa Office Pond	24
Table 2.5: Example of SOL method results for TSS in the Tampa Office Pond.....	25
Table 2.6: Example of ROL method results for TSS in the Tampa Office Pond.	27
Table 2.7: Example of Individual Storm Loads Method results for TSS in the Tampa Office Pond.....	32
Table 2.8: Comparison of BMP efficiency methods.....	32
Table 2.9: “Irreducible concentrations” as reported by Scheuler, 2000.	33
Table 2.10: Example TSS results for typical ER Method.....	33
Table 2.11: Example TSS results for demonstration of Relative Efficiency approach.....	35
Table 2.12: Example of percent removal relative to receiving water quality limits approach.....	36
Table 3.1: Typical urban stormwater runoff constituents and recommended detection limits	79
Table 3.2: Flow measurement methods.....	91
Table 3.3: Equipment for measuring depth of flow	103
Table 3.4: Velocity measurement methods suitable for calibration.....	108
Table 3.5: National Stormwater BMP Database requirements for all BMPs	149
Table 3.6: National Stormwater BMP Database requirements for structural BMPs.....	150
Table 3.7: National Stormwater BMP Database requirements for Non-structural BMPs	150
Table 3.8: National Stormwater BMP Database requirements for individual structural BMPs	151
Table 3.9: National Stormwater BMP Database requirements for non-structural BMPs and structural BMPs that are based on minimizing directly connected impervious areas	156
Table 3.10: National Stormwater BMP Database requirements for structural BMPs that are based on minimizing directly connected impervious areas	157
Table 3.11: General test site form data element descriptions	158
Table 3.12: Watershed form data elements description	160
Table 3.13: Structural BMP form data elements description.....	165
Table 3.14: Non-structural BMP form data elements description	167
Table 3.15: Detention Basin design form data elements list.....	170

Table 3.16:	Retention Pond design form data elements list	173
Table 3.17:	Percolation trench and dry well design form data elements list	176
Table 3.18:	Media filter design form data elements list.....	179
Table 3.19:	Grass filter strip form data elements list	182
Table 3.20:	Wetland channel and swale form data elements list	184
Table 3.21:	Porous pavement form data elements	187
Table 3.22:	Infiltration basin form data elements list.....	190
Table 3.23:	Hydrodynamic device form data elements.....	193
Table 3.24:	Wetland basin form data elements list.....	195
Table 3.25:	Monitoring station form data elements	199
Table 3.26:	Precipitation form data elements	202
Table 3.27:	Flow form data elements.....	204
Table 3.28:	Water quality form data elements.....	206
Table A.1:	Example of inputs for estimation of errors in flow measurement Devices.....	A-5
Table A.2:	Summary of examples demonstrating the propagation of errors in flow measurement.....	A-7
Table D.1:	Relationships of log-normal distributions.....	D-1

List of Figures

	Page
Figure 2.1 ROL plot for use in calculating efficiency for TSS using the Tampa Office Pond (1990).....	28
Figure 2.2 ROL plot for use in calculating efficiency for TSS using the Tampa Office Pond (1993-1994).....	28
Figure 2.3 ROL plot for use in calculating efficiency for TSS using the Tampa Office Pond (1994-1995)	29
Figure 2.4 Removal Efficiency (ER Method) of TSS as a function of influent concentration	38
Figure 2.5 Removal Efficiency (ER Method) of total phosphorous as a function of influent concentration.....	38
Figure 2.6 Removal Efficiency (ER Method) of total zinc as a function of influent concentration.....	39
Figure 2.7 Percent removal as a function of influent concentration for randomly generated, normally distributed influent and effluent concentrations.	39
Figure 2.8 Probability plot for Suspended Solids.....	42
Figure 2.9 Probability plot for Total Dissolved Solids	42
Figure 2.10 Probability plot for Chemical Oxygen Demand	42
Figure 3.1 Nomograph relating coefficient of variation of a samples set to the allowable error in the estimate of the population mean.....	71
Figure 3.2 Number of samples required using a paired sampling approach to observe a statistically significant percent difference in mean concentration as a function of the coefficient of variation (power of 80% and confidence of 95%)	75
Figure 3.3 Data logger with weatherproof housing.....	84
Figure 3.4 Data logger without housing.....	85
Figure 3.5 Data logger summary.....	88
Figure 3.6 Parshall flume	98
Figure 3.7 H-flume	98
Figure 3.8 Bubbler flow meter	104
Figure 3.9 Ultrasonic-depth sensor module	105
Figure 3.10 Pressure transducers.....	106
Figure 3.11 Area velocity sensors module	110
Figure 3.12 Automatic sampler	116
Figure 3.13 VOC sampler	117
Appendix B Figures: Number of samples required for various powers, confidence intervals, and percent differences	B-1

Acknowledgements and Disclaimer

The authors, Eric Strecker, P.E. of GeoSyntec Consultants, Ben Urbonas, P.E. Urban Drainage and Flood Control District, Denver, Marcus Quigley, P.E., Jim Howell, and Todd Hesse of GeoSyntec Consultants would like to thank Jesse Pritts, P.E. and Eric Strassler of the Environmental Protection Agency and Tom McLane and Lorena Diaz of the American Society of Civil Engineers (ASCE) for their support for and participation in the ASCE/EPA National Stormwater Best Management Practices Database Project and the development of this guidance. The authors would also like to thank the following members of ASCE's Urban Water Resources Research Council for their thorough review and contributions to this guidance:

Robert Pitt, P.E., Ph.D. (University of Alabama, Birmingham)
Eugene Driscoll, P.E.
Roger Bannerman, P.E. (Wisconsin Department of Natural Resources)
Shaw Yu, P.E., Ph.D. (University of Virginia)
Betty Rushton (Southwest Florida Water Management District)
Richard Field (EPA), P.E.
Jonathan Jones, P.E. (Wright Water Engineers)
Jane Clary (Wright Water Engineers)
Tom Langan (Wright Water Engineers)

Sections of this manual were developed by the authors concurrently with the Federal Highway Administration's (FHWA) "Guidance Manual For Monitoring Highway Runoff Water Quality." Although the focus of the FHWA manual is on highway runoff monitoring, much of the information on equipment selection, use, and installation is applicable to best management practice monitoring and thus was adapted for this guidance.

In addition, portions of this document were adapted from work originally conducted for the Washington State Department of Ecology's (DOE) November 1995, "Stormwater Monitoring Guidance Manual" by an author of this document (Eric Strecker) and Mike Milne (Brown and Caldwell), Terry Cook (URS Group, Inc.), Gail Boyd (URS Group, Inc.), Krista Reininga (URS Group, Inc.), and Lynn Krasnow. The thoroughness and specific insight provided in the DOE Manual were useful in assembling this guidance.

The authors would also like to thank Joan LeBlanc, and Kathy Staffier (GeoSyntec Consultants) for editorial review and edits of the final document.

Disclaimer:

Mention of trade names or commercial products does not constitute endorsement by EPA or ASCE, or recommendation for use.